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Chemical Reaction Effect on Unsteady MHD Flow Past an Exponentially Accelerated Inclined Plate with Variable Temperature and Mass Diffusion in the Presence of Hall Current

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Chemical reaction effect on unsteady MHD flow past an exponentially accelerated inclined plate with variable temperature and mass diffusion in the presence of Hall current is studied here. The fluid considered is gray, absorbing-emitting radiation but a non-scattering medium. The Governing equations involved in the present analysis are solved by the Laplace-transform technique. The velocity profile is discussed with the help of graphs drawn for different parameters like Grashof number, mass Grashof Number, Prandtl number, Chemical reaction parameter, Hall current parameter, accelerated parameter, the magnetic field parameter and Schmidt number, and the numerical values of skin-friction and Sherwood number have been tabulated.

***Keywords**: MHD flow, exponentially accelerated inclined plate, variable temperature, mass diffusion and Hall current.*

1. Introduction

MHD flow problems associated with chemical reaction play important roles in different areas of science and technology, like chemical engineering, mechanical engineering, biological science, petroleum engineering and biomechanics. The influence of magnetic field on viscous, incompressible and electrically conducting fluid is of great importance in many applications such as magnetic material processing, glass manufacturing control processes and purification of crude oil. MHD flow past an impulsively started vertical plate with variable temperature and mass diffusion was investigated by Rajput and Kumar[14]. Singh and Kumar[2] have considered free convection flow past an exponentially accelerated vertical plate. Basant et al[3] have worked on mass transfer effects on the flow past an exponentially accelerated vertical plate with constant heat flux.

Muthucumaraswamy et al[12] have considered Heat transfer effects on flow past an exponentially accelerated vertical plate with variable temperature. Further Muthucumaraswamy[13] et al have studied mass transfer effects on exponentially accelerated isothermal vertical plate. Chemical reaction effect on MHD flow is also significant in many cases. Some such problems already studied are mentioned here. Effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction was analyzed by Das et al[4]. Anjalidevi and Kandasamy[6] have studied effect of a chemical reaction heat and mass transfer on MHD flow past a semi infinite plate. Muthucumarswamy[7] has investigated effects of chemical reaction on a moving isothermal vertical surface with suction. Raptis and Perdikis[10] have worked on viscous flow over a non-linearly stretching sheet in the presence of a chemical reaction and magnetic field. Some papers related with Hall effect are also mentioned here. Hall effects on MHD flow past an accelerated plate was considered by Deka[11]. Katagiri[1] has considered the effect of Hall current on the magneto hydrodynamic boundary layer flow past a semi-infinite fast plate. Hall effects on magnetohydrodynamic boundary layer flow over a continuous moving flat plate was studied by Pop and Watanabe[5]. Attia[8] has analyzed the effect of variable properties on the unsteady Hartmann flow with heat transfer considering the Hall effect. The Hall effect on unsteady MHD Couette flow with heat transfer of a Bingham fluid with suction and injection was investigated by Attia and Sayed[9]. Srinivas and Kishan[15] have investigated Hall effect on unsteady MHD free convection flow over a stretching sheet with variable viscosity and viscous dissipation. We are considering chemical reaction effect on unsteady MHD flow past an exponentially accelerated inclined plate with variable temperature and mass diffusion in the presence of Hall current. The results are shown with the help of graphs and table.

2. Mathematics Analysis.

MHD flow between two parallel electrically non conducting plates inclined at an angle α from vertical is considered. x axis is taken along the plane and z normal to it. A transverse magnetic field B_0 of uniform strength is applied on the flow. Initially it has been considered that the plate as well as the fluid is at the same temperature T_∞. The species concentration in the fluid is taken as C_∞. At time $t > 0$, the plate starts exponentially accelerating in its own plane with velocity $u=u_0.e^{bt}$ and temperature of the plate is raised to T_w. The concentration C near the plate is raised linearly with respect to time. The flow modal is as under:

$$\frac{\partial u}{\partial t} = \upsilon \frac{\partial^2 u}{\partial z^2} + g\beta Cos\alpha\,(T - T_\infty) + g\beta^* Cos\alpha\,(C - C_\infty) - \frac{\sigma B_0^2 (u + mv)}{\rho(1 + m^2)}, \qquad (1)$$

$$\frac{\partial v}{\partial t} = \upsilon \frac{\partial^2 v}{\partial z^2} + \frac{\sigma B_0^2 (mu - v)}{\rho (1+m^2)}, \tag{2}$$

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial z^2} - K_C (C - C_\infty), \tag{3}$$

$$\rho C_p \frac{\partial T}{\partial t} = k \frac{\partial^2 T}{\partial z^2}. \tag{4}$$

The initial and boundary conditions are:

$$\left.\begin{array}{l} t \le 0 : u = 0,\ v = 0,\ T = T_\infty,\ C = C_\infty, \text{for all } z, \\ t > 0 : u = u_0 e^{bt},\ v = 0, T = T_\infty + (T_w - T_\infty)\dfrac{u_0^2 t}{\upsilon}, \quad \text{at } z=0, \\ C = C_\infty + (C_w - C_\infty)\dfrac{u_0^2 t}{\upsilon}, \\ u \to 0,\ v \to 0,\ T \to T_\infty,\ C \to C_\infty \text{ as } z \to \infty. \end{array}\right\} \tag{5}$$

Here u is the Primary velocity, v -the secondary velocity, g-the acceleration due to gravity, β -volumetric coefficient of thermal expansion, b-acceleration parameter, t-time, $m(=\omega_e \tau_e)$ is the Hall parameter with ω_e-cyclotron frequency of electrons and τ_e- electron collision time, T -temperature of the fluid, β^*-volumetric coefficient of concentration expansion, C- species concentration in the fluid, ν -the kinematic viscosity, ρ - the density, C_p- the specific heat at constant pressure, k- thermal conductivity of the fluid, D-the mass diffusion coefficient, T_w-temperature of the plate at z= 0, C_w-species concentration at the plate z= 0, B_0 - the uniform magnetic field, K_c - chemical reaction, σ - electrical conductivity.

The following non-dimensional quantities are introduced to transform equations (1), (2), (3) and (4) into dimensionless form:

$$\left.\begin{array}{l} \bar{z} = \dfrac{z u_0}{\upsilon},\ \bar{u} = \dfrac{u}{u_0},\ \bar{v} = \dfrac{v}{u_0}, S_c = \dfrac{\upsilon}{D},\ \mu = \rho\upsilon,\ M = \dfrac{\sigma B_0^2 \upsilon}{\rho u_0^2}, \\ K_0 = \dfrac{\upsilon K_C}{u_0^2}, P_r = \dfrac{\mu c_p}{k}, G_r = \dfrac{g\beta\upsilon(T_w - T_\infty)}{u_0^3}, \theta = \dfrac{(T - T_\infty)}{(T_w - T_\infty)}, \\ G_m = \dfrac{g\beta^* \upsilon (C_w - C_\infty)}{u_0^3},\ \bar{C} = \dfrac{(C - C_\infty)}{(C_w - C_\infty)}, \bar{t} = \dfrac{t u_0^2}{\upsilon}. \end{array}\right\} \tag{6}$$

Where $\bar{u}$ is the dimensionless primary velocity, $\bar{v}$ -the secondary velocity, $\bar{b}$ -dimensionless acceleration parameter, $\bar{t}$ -dimensionless time, θ -the dimensionless temperature, $\bar{C}$ -the dimensionless concentration, G_r - thermal Grashof number, G_m - mass Grashof number, μ - the coefficient of viscosity, K_0 -chemical reaction parameter, P_r - the Prandtl number, S_c - the Schmidt number, M- the magnetic parameter.

Then the model becomes:

$$\frac{\partial \bar{u}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + G_r Cos\,\alpha\,\theta + G_m Cos\,\alpha\,\bar{C} - \frac{M(\bar{u} + m\bar{v})}{(1+m^2)}, \quad (7)$$

$$\frac{\partial \bar{v}}{\partial \bar{t}} = \frac{\partial^2 \bar{u}}{\partial \bar{z}^2} + \frac{M(m\bar{u} - \bar{v})}{(1+m^2)}, \quad (8)$$

$$\frac{\partial \bar{C}}{\partial \bar{t}} = \frac{1}{S_c}\frac{\partial^2 \bar{C}}{\partial \bar{z}^2} - K_0 \bar{C}, \quad (9)$$

$$\frac{\partial \theta}{\partial \bar{t}} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial \bar{z}^2}. \quad (10)$$

The boundary conditions become:

$$\left.\begin{array}{l} \bar{t} \le 0 : \bar{u} = 0,\ \bar{v} = 0,\ \theta = 0,\ \bar{C} = 0, \text{ for all } \bar{z}, \\ \bar{t} > 0 : \bar{u} = e^{\bar{b}\bar{t}},\ \bar{v} = 0,\ \theta = \bar{t},\ \bar{C} = \bar{t}, \text{ at } \bar{z} = 0, \\ \bar{u} \to 0,\ \bar{v} \to 0,\ \theta \to 0,\ \bar{C} \to 0, \text{ as } \bar{z} \to \infty. \end{array}\right\} \quad (11)$$

Dropping bars in the above equations, we get:

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial z^2} + G_r Cos\,\alpha\,\theta + G_m Cos\,\alpha\,C - \frac{M(u + mv)}{(1+m^2)}, \quad (12)$$

$$\frac{\partial v}{\partial t} = \frac{\partial^2 v}{\partial z^2} + \frac{M(mu - v)}{(1+m^2)}, \quad (13)$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} - K_0 C, \quad (14)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}. \tag{15}$$

The corresponding boundary conditions are:

$$\left.\begin{array}{l} t \le 0 : u = 0,\ v = 0,\ \theta = 0,\ C = 0, \text{ for all } z, \\ t > 0 : u = e^{bt},\ v = 0,\ \theta = t,\ C = t, \quad \text{at } z = 0, \\ u \to 0,\ v \to 0,\ \theta \to 0,\ C \to 0, \text{ as } z \to \infty. \end{array}\right\} \tag{16}$$

Writing the equations (12) and (13) in Combined form:

$$\frac{\partial q}{\partial t} = \frac{\partial^2 q}{\partial z^2} + G_r Cos\alpha\, \theta + G_m Cos\alpha\, C - qa, \tag{17}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_c}\frac{\partial^2 C}{\partial z^2} - K_0 C, \tag{18}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{P_r}\frac{\partial^2 \theta}{\partial z^2}. \tag{19}$$

The boundary conditions are transformed to:

$$\left.\begin{array}{l} t \le 0 : q = 0, \theta = 0, C = 0, \text{ for all z,} \\ t > 0 : q = e^{bt}, \theta = t, C = t, \text{ at z=0,} \\ q \to 0,\ \theta \to 0,\ C \to 0, \text{ as } z \to \infty. \end{array}\right\} \tag{20}$$

Here $q = u + i\,v$, $a = \frac{M\,(1 - im)}{1 + m^2}$.

The dimensionless governing equations (17) to (19), subject to the boundary conditions (20), are solved by the usual Laplace - transform technique.
The solution obtained is as under:

$$\theta = t\left\{ (1 + \frac{z^2 P_r}{2t}) erfc[\frac{\sqrt{P_r}}{2\sqrt{t}}] - \frac{z\sqrt{P_r}}{\sqrt{\pi}\sqrt{t}} e^{-\frac{z^2}{4t} P_r} \right\},$$

$$C = \frac{e^{-z\sqrt{S_c K_0}}}{4\sqrt{K_0}} \{erfc[\frac{z\sqrt{S_c} - 2t\sqrt{K_0}}{2\sqrt{t}}](-z\sqrt{S_c} + 2t\sqrt{K_0}) + e^{2z\sqrt{S_c K_0}}$$
$$erfc[\frac{z\sqrt{S_c} + 2t\sqrt{K_0}}{2\sqrt{t}}](z\sqrt{S_c} + 2t\sqrt{K_0})\}$$

$$q = \frac{1}{2} e^{bt-\sqrt{a+bz}} A_{15} + \frac{G_r Cos\alpha}{4a^2}\left[zA_{11} + 2e^{-\sqrt{a}z} A_2 P_r + 2A_{14}A_4(1-P_r)\right] +$$
$$\frac{G_m Cos\alpha}{4(a-K_0 S_c)^2}[zA_{11} + 2A_{13}A_5(1-S_c) + 2e^{-\sqrt{a}z}A_2 S_c(1-tK_0) -$$
$$\frac{ze^{-\sqrt{a}z} A_3 K_0 S_c}{\sqrt{a}}] + \frac{G_r Cos\alpha}{2a^2\sqrt{\pi}}[2zae^{\frac{-z^2 P_r}{4t}}\sqrt{tP_r} + \sqrt{\pi}A_{14}(A_6 + A_7 P_r) +$$
$$\sqrt{\pi}A_{12}(az^2 P_r - 2 + 2at + 2P_r)] + \frac{G_m Cos\alpha}{4\sqrt{\pi}(a-K_0 S_c)^2}[\frac{e^{-\sqrt{K_0 S_c}}\sqrt{\pi}A_9\sqrt{S_c}}{2\sqrt{K_0}}$$
$$(S_c K_0 - az) + A_{13}\sqrt{\pi}A_{10}(S_c - 1) + e^{-\sqrt{K_0 S_c}}\sqrt{\pi}A_8(1 - at - S_c + tK_0 S_c)]$$

The expressions for the constants involved in the above equations are given in the appendix.

3. Skin friction

The dimensionless skin friction at the plate z=0 is as follows:

$$\left(\frac{dq}{dz}\right)_{z=0} = \tau_x + i\tau_y \ .$$

Separating real and imaginary part in $\left(\frac{dq}{dz}\right)_{z=0}$, the dimensionless skin friction component $\tau_x = \left(\frac{du}{dz}\right)_{z=0}$ and $\tau_y = \left(\frac{dv}{dz}\right)_{z=0}$ can be computed

4. Sherwood number

The dimensionless Sherwood number at the plate z=0 is given by

$$S_h = \left(\frac{\partial C}{\partial z}\right)_{z=0} = erfc[\,-\sqrt{tK_0}\,](-\frac{1}{4\sqrt{K_0}}\sqrt{S_c} - \frac{t\sqrt{S_c K_0}}{2}) + \sqrt{S_c}\,erfc[\,\sqrt{tK_0}\,]$$

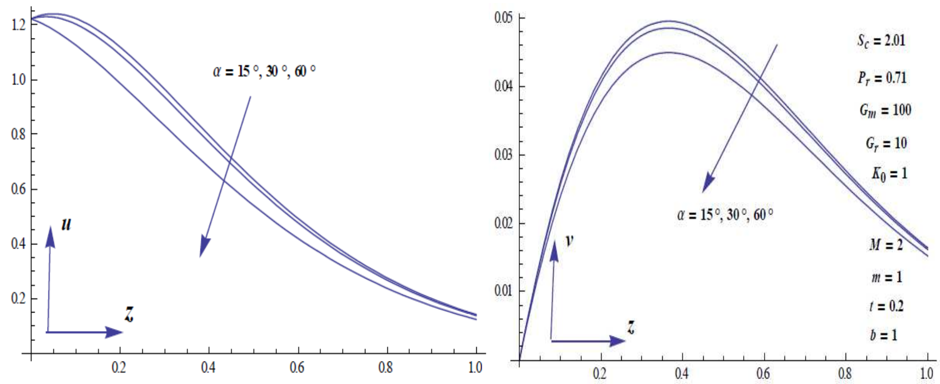
$$(\frac{1}{4\sqrt{K_0}} + t\sqrt{K_0}\,) - \frac{e^{-tK_0}\sqrt{tS_c K_0}}{\sqrt{\pi K_0}},$$

4. Results and Discussion

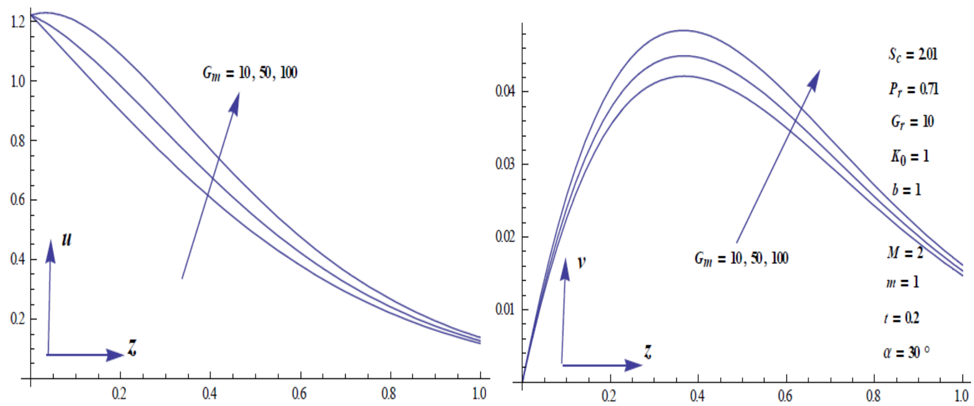
The velocity profile for different parameters like, thermal Grashof number (*Gr*), magnetic field parameter (*M*), Hall parameter (*m*), Prandtl number (*Pr*), chemical reaction parameter(K_0), acceleration parameter (*b*) and time (t) is shown in figures 1.1 to 2.10. It is observed from figures 1.1 and 2.1 that the primary and secondary velocities of fluid decrease when the angle of inclination (α) is increased. It is observed from figure 1.2 and 2.2, when the mass Grashof number *Gr* is increased then the velocities are increased. From figures 1.3 and 2.3 it is deduced that velocities increase with thermal Grashof number *Gr*. if Hall current parameter *m* is increased then u increases, while *v* gets decreased (figures 1.4 and 2.4). Further, it is observed from figures 1.5 and 2.5 that the effect of increasing values of the parameter *M* results in decreasing u and increasing v. It is deduced that when chemical reaction parameter K_0 is increased then the velocities are decreased (figures 1.6 and 2.6). It is observed from figures 1.7 and 2.7 that when acceleration parameter *b* increases then the velocities are increased. Further, it is observed that velocities decrease when Prandtl number and Schmidt number are increased (figures 1.8, 2.8, 1.9 and 2.9). From figures 1.10 and 2.10, it is observed that velocities increase with time. The concentration profiles for chemical reaction parameter and Schmidt number are shown in figures 3.1 and 3.2. From both the profiles, a decreasing pattern is observed.

Skin friction is given in table1. The value of τ_x increases with the increase in the angle of inclination of plate, thermal Grashof Number, Hall current parameter, the magnetic field parameter, Schmidt number, and it decreases with the mass Grashof number, chemical reaction parameter, acceleration parameter, Prandtl number and time. Similar effect is observed with τ_y, except chemical reaction parameter, Hall parameter and acceleration parameter; where τ_y increases with chemical reaction parameter and acceleration parameter, and decreases with Hall parameter.

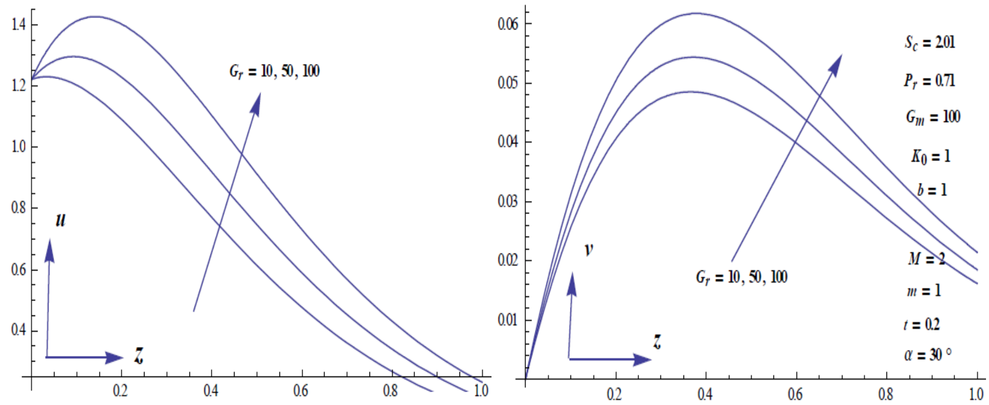
Sherwood number is given in table2. The value of S_h decreases with the increase in the chemical reaction parameter, Schmidt number and time.



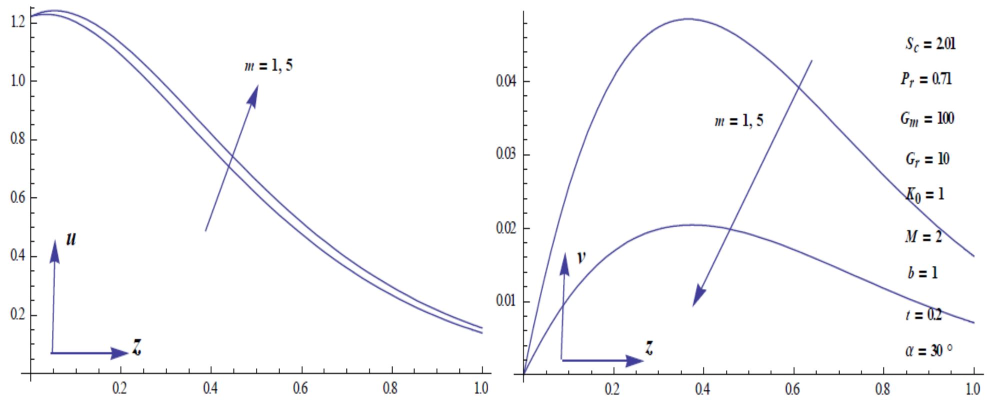
Figures 1.1 & 2.1. Velocities u and v for different values of α



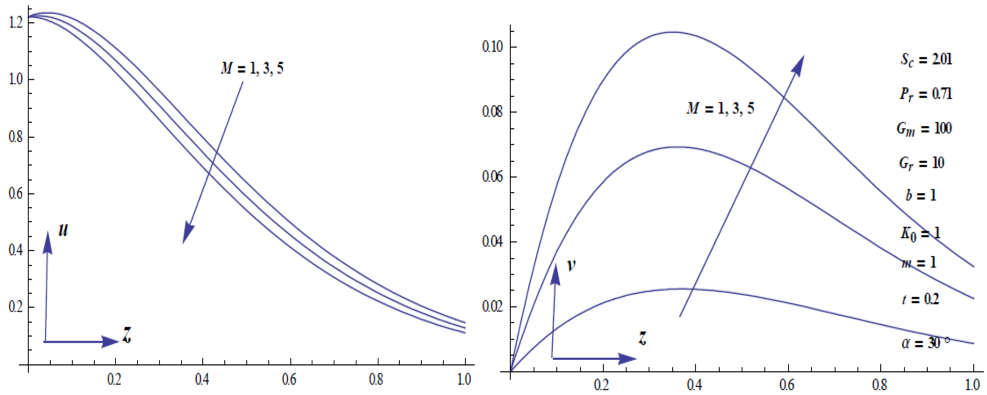
Figures 1.2 & 2.2. Velocities u and v for different values of *Gm*



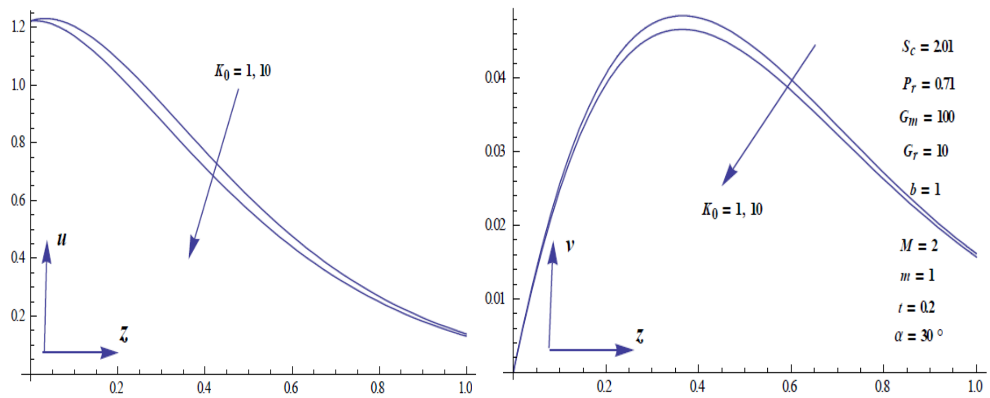
Figures 1.3 & 2.3. Velocities u and v for different values of *Gr*



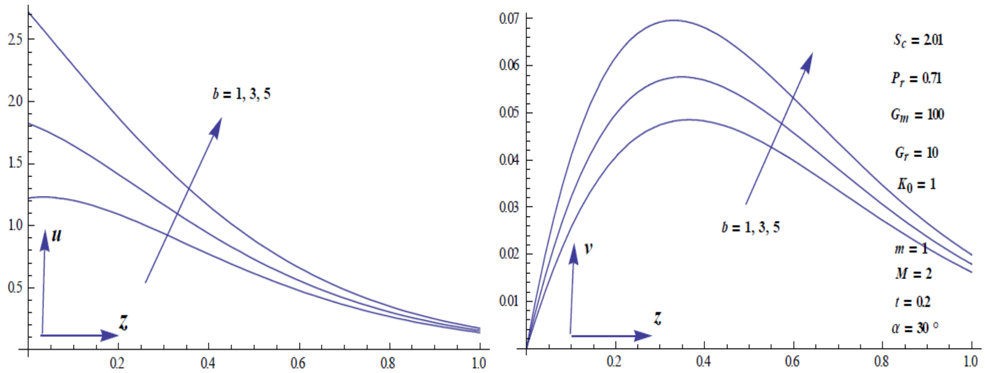
Figures 1.4 & 2.4. Velocities u and v for different values of *m*



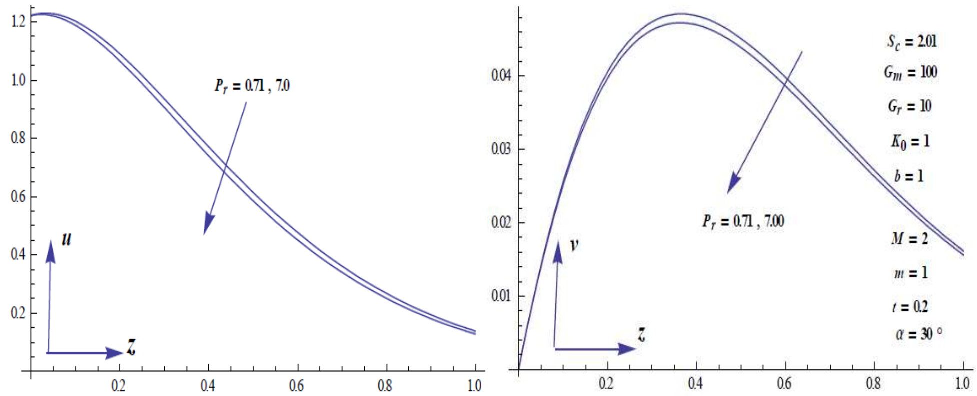
Figures 1.5 & 2.5. Velocities u and v for different values of *M*



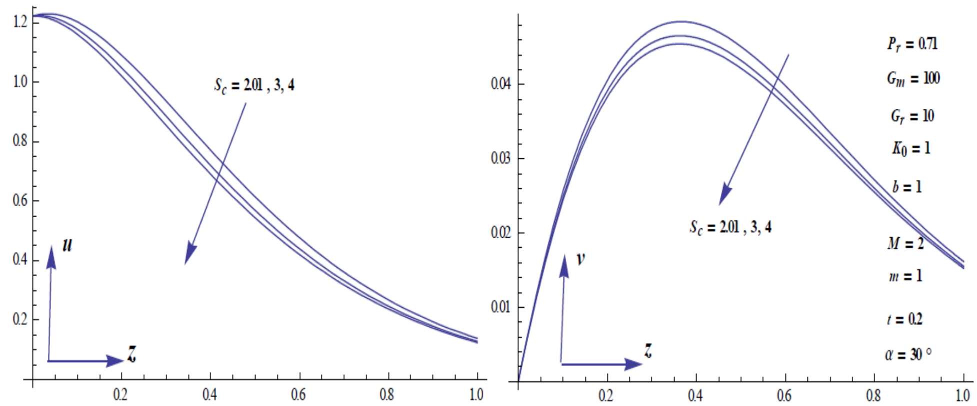
Figures 1.6 & 2.6. Velocities u and v for different values of K_0



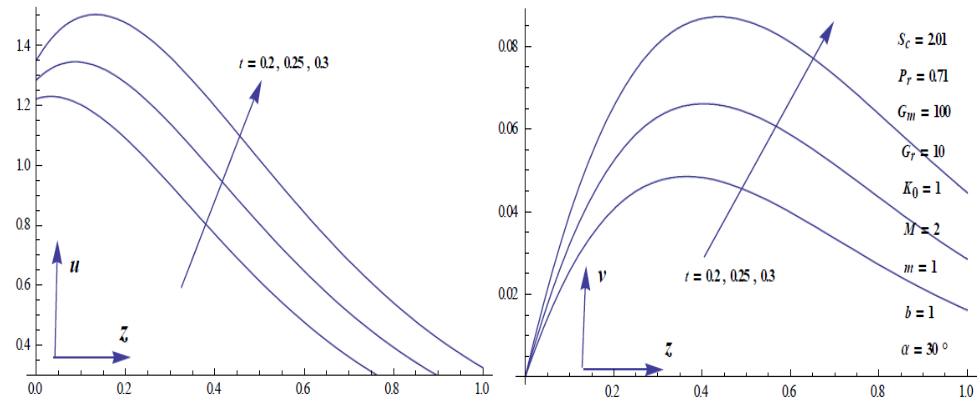
Figures 1.7 & 2.7. Velocities u and v for different values of *b*



Figures 1.8 & 2.8. Velocities u and v for different values of *Pr*



Figures 1.9 & 2.9. Velocities u and v for different values of *Sc*



Figures 1.10 & 2.10. Velocities u and v for different values of *t*

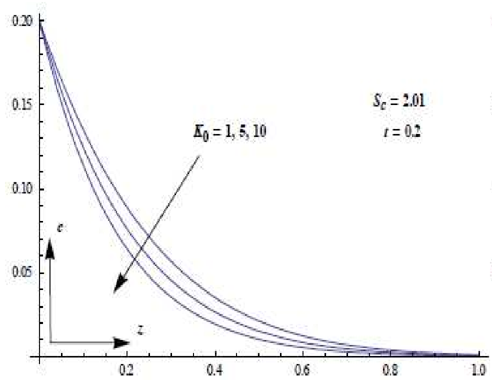


Figure 3.1. c for different values of K_0

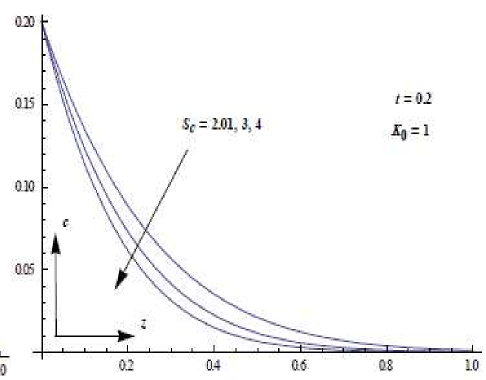


Figure 3.2. c for different values of *Sc*

Table1. Skin friction for different Parameters.

α (in degrees)	*M*	*m*	*Pr*	*Sc*	*Gm*	*Gr*	K_0	*t*	*b*	τ_x	τ_y
15	2	1	0.71	2.01	100	10	1	0.2	1	-19.467	-6.66175
30	2	1	0.71	2.01	100	10	1	0.2	1	-17.6736	-5.94470
60	2	1	0.71	2.01	100	10	1	0.2	1	-11.1030	-3.31700
30	3	1	0.71	2.01	100	10	1	0.2	1	-19.6470	7.718940
30	5	1	0.71	2.01	100	10	1	0.2	1	-4.19511	13.46340
30	2	3	0.71	2.01	100	10	1	0.2	1	-9.33424	9.965630
30	2	5	0.71	2.01	100	10	1	0.2	1	-8.64520	-15.6939
30	2	1	7.00	2.01	100	10	1	0.2	1	-17.8249	-5.94949
30	2	1	0.71	3.00	100	10	1	0.2	1	-5.16762	-7.49358
30	2	1	0.71	4.00	100	10	1	0.2	1	-1.68272	-4.89463

30	2	1	0.71	2.01	10	10	1	0.2	1	-3.40352	-0.34450
30	2	1	0.71	2.01	50	10	1	0.2	1	-9.74580	-2.83348
30	2	1	0.71	2.01	100	50	1	0.2	1	-16.4361	-5.91883
30	2	1	0.71	2.01	100	100	1	0.2	1	-14.8892	-5.88650
30	2	1	0.71	2.01	100	10	5	0.2	1	0.419897	-0.73174
30	2	1	0.71	2.01	100	10	10	0.2	1	0.204496	-0.02182
30	2	1	0.71	2.01	100	10	1	0.3	1	-24.6871	-8.92858
30	2	1	0.71	2.01	100	10	1	0.4	1	-31.4792	-11.8761
30	2	1	0.71	2.01	100	10	1	0.2	3	-19.4828	-5.85459
30	2	1	0.71	2.01	100	10	1	0.2	5	-22.4414	-5.72883

Table2. Sherwood number for different Parameters.

K_0	Sc	t	S_h
1	2.01	0.2	-0.762200
5	2.01	0.2	-0.933049
10	2.01	0.2	-1.118240
1	3.00	0.2	-0.931175
1	4.00	0.2	-1.075230
1	2.01	0.3	-0.961323
1	2.01	0.4	-1.141570

4. Conclusion

The conclusions of the study are as follows:

- Primary velocity increases with the increase in thermal Grashof number, mass Grashof number, Hall current parameter, acceleration parameter and time.
- Primary velocity decreases with angle of inclination of plate, the magnetic field, chemical reaction parameter, Prandtl number and Schmidt number.
- Secondary velocity increases with the increase in thermal Grashof number, mass Grashof number, the magnetic field, acceleration parameter and time.
- Secondary velocity decreases with the angle of inclination of the plate, Hall current parameter, chemical reaction parameter, Prandtl number and Schmidt number.
- τ_x increases with the increase in α Gr, m, M and $Sc,$ and it decreases with Gm, b, K_0 ,Pr and t.
- τ_y increases with the increase in α , Gr, K_0 , b, M and $Sc,$ and it decreases with Gm, m, Pr and t.
- S_h decreases with the increase in K_0 , Sc and t.

Appendex

$$A_1 = 1 + A_{16} + e^{2\sqrt{az}}(1 - A_{17}),\ \ A_2 = -A_1,\ \ A_3 = A_{16} - A_1,$$

$$A_4 = -1 + A_{22} + A_{18}(A_{23} - 1),\quad A_5 = -1 + A_{24} + A_{19}(A_{25} - 1),$$

$$A_6 = -1 - A_{26} + A_{18}(A_{27} - 1),\quad A_7 = -A_6,\ \ A_8 = -1 - A_{20} + A_{30}(A_{21} - 1),$$

$$A_9 = A_8 + 2(A_{20} + 1),\ \ A_{10} = -1 - A_{28} + A_{19}(A_{29} - 1),$$

$$A_{11} = \frac{e^{-\sqrt{az}}}{z}(2A_1 + 2atA_2 + \sqrt{a}A_3),\quad A_{12} = -1 + erf\left[\frac{z\sqrt{P_r}}{2\sqrt{t}}\right],$$

$$A_{13} = e^{\frac{at}{-1+S_c} - z\sqrt{\frac{(a-K_0)S_c}{-1+S_c}} - \frac{tK_0S_c}{-1+S_c}},\quad A_{14} = e^{\frac{at}{-1+P_r} - z\sqrt{\frac{(a)P_r}{-1+P_r}}},$$

$$A_{15} = 1 + A_{31} + e^{2\sqrt{a+bz}}A_{32},\ \ A_{16} = erf[\frac{2\sqrt{at} - z}{2\sqrt{t}}],$$

$$A_{17} = erf[\frac{2\sqrt{at} + z}{2\sqrt{t}}],\quad A_{18} = e^{-2z\sqrt{\frac{aP_r}{-1+P_r}}},\ A_{19} = e^{-2z\sqrt{\frac{(a-K_0)S_c}{-1+S_c}}},$$

$$A_{20} = erf\left[\sqrt{tK_0} - \frac{z\sqrt{S_c}}{2\sqrt{t}}\right],\quad A_{21} = erf\left[\sqrt{tK_0} + \frac{z\sqrt{S_c}}{2\sqrt{t}}\right],$$

$$A_{22} = erf\,[\frac{z - 2t\sqrt{\frac{aP_r}{-1+P_r}}}{2t}],\quad A_{23} = erf\,[\frac{z + 2t\sqrt{\frac{aP_r}{-1+P_r}}}{2t}],$$

$$A_{24} = erf\,[\frac{z - 2t\sqrt{\frac{(a-K_0)S_c}{-1+S_c}}}{2t}],\ \ A_{25} = erf\,[\frac{z + 2t\sqrt{\frac{(a-K_0)S_c}{-1+S_c}}}{2t}],$$

$$A_{26} = erf[\frac{2t\sqrt{\frac{a}{-1+P_r}} - z\sqrt{P_r}}{2\sqrt{t}}],\ \ A_{27} = erf[\frac{2t\sqrt{\frac{a}{-1+P_r}} + z\sqrt{P_r}}{2\sqrt{t}}],$$

$$A_{28} = erf[\sqrt{t}\sqrt{\frac{(a-K_0)}{-1+S_c}} - \frac{zS_c}{2\sqrt{t}}],\quad A_{29} = erf[\sqrt{t}\sqrt{\frac{(a-K_0)}{-1+S_c}} + \frac{zS_c}{2\sqrt{t}}],$$

$$A_{30} = erf[e^{2z\sqrt{K_0\sqrt{S_c}}}],\ A_{31} = erf[\frac{2\sqrt{a+bt} - z}{2\sqrt{t}}],\ A_{32} = erfc[\frac{2\sqrt{a+bt} + z}{2\sqrt{t}}].$$

References

[1] Katagiri M., *The Effect of Hall Current on the Magneto hydrodynamic Boundary layer Flow Past a Semi-infinite Fast Plate*, Journal of the Physical Society of Japan, Vol. 27(4), (1969), pp. 1051-1059.

[2] Singh A.K., Naveen Kumar, *Free convection flow past an exponentially accelerated vertical plate*, Astrophysics and Space Science 98, (1984), 245-258.

[3] Basant K.J., Prasad R., Rai S., '*Mass transfer effects on the flow past an exponentially accelerated vertical plate with constant heat flux*, Astrophysics and Space Science 81, (1991), 125-134.

[4] Das U.N., Deka R.K., Soundalgekar V.M., *Effects of mass transfer on flow past an impulsively started infinite vertical plate with constant heat flux and chemical reaction*, Forsch. Ingenieurwes 60, (1994), 2 84-287.

[5] Pop I., Watanabe T., *Hall effects on magnetohydrodynamic boundary layer flow over a continuous moving flat plate*, Acta Mech., (1995), Vol. 108, pp. 35–47.

[6] Anjalidevi S.P., Kandasamy R., *Effect of a chemical reaction heat and mass transfer on MHD flow past a semi infinite plate*, ZAMM, 80, (2000), 697-701.

[7] Muthucumarswamy R., *Effects of chemical reaction on a moving isothermal vertical surface with suction*, Acta Mech.155, (2002), 65-70.

[8] Attia H.A., *The effect of variable properties on the unsteady Hartmann flow with heat transfer considering the Hall effect*, Appl. Math. Model. 27 (7) , (2003), 551–563.

[9] Attia H.A., Ahmed Mohamed Eissa Sayed, *The Hall effect on unsteady MHD Couette flow with heat transfer of a Bingham fluid with suction and injection*, Applied Mathematical Modelling 28 (2004) 1027-1045.

[10] Raptis A., Perdikis C., *Viscous flow over a non-linearly stretching sheet in the presence of a chemical reaction and magnetic field*, International Journal of Non- Linear Mechanics 41, (2006), 527-529.

[11] Deka R.K., *Hall effects on MHD flow past an accelerated plate*, Theoret. Appl. Mech., Belgrade (2008), Vol.35, No.4, pp. 333-346.

[12] Muthucumaraswamy R., Sathappan K.E., Natarajan R., *Heat transfer effects on flow past an exponentially accelerated vertical plate with variable temperature*', Theoret. Appl. Mech., (2008), 35, 4, 323 -331.

[13] Muthucumaraswamy R., Sathappan K.E., Natarajan R., *Mass transfer effects on exponentially accelerated isothermal vertical plate*', Int. J. of Appl. Math. and Mech. 4(6), (2008), 19- 25.

[14] Rajput U.S., Kumar Surendra, *MHD Flow Past an Impulsively Started Vertical Plate with Variable Temperature and Mass Diffusion*, Applied Mathematical Sciences, Vol. 5, no. 3, (2011), 149 – 157.

[15] Maripala Srinivas, Naikoti Kishan, *Hall Effects on Unsteady MHD Free Convection Flow over a Stretching Sheet with Variable Viscosity and Viscous Dissipation,* World Applied Sciences Journal 33 (6), (2015), 1032-1041.

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